

Medical Education, Research and Practice in the Information Age

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Computer literacy has the same role and ought to be taken for granted in much the same way as book literacy. In principle, students need not know about electronic circuitry or software compilers any more than they need know about the mechanics of the printing press. A primary barrier to computer literacy, however, is fear about interfacing with a terminal, and this is perhaps more acute in the middle-aged than in younger students. They must become sufficiently familiar with the terminal so that they are not overawed. The information that comes from the terminal is exactly as reliable as the information that was put into it, just as the information in the daily press or the printed volume deserves no more credit than is due its sources, with the exception that it is exposed to the critical judgment of the community.

Besides the role of computers as books, there is the very important function of computers as instruments. In this capacity they are more and more embedded into daily medical practice. We have CT scanners, NMR scanners and similar devices. As unit prices plummet we will see more office-based instrumentation proliferating in the diagnostic enterprise, assisting the physician. Again, the physician does not have to know every detail of the electronic circuitry that controls the X-ray machine, but it is better if he does know something about it. This general knowledge is necessary not only for a sense of the limitations of the technology, but also so the user can identify new opportunities for innovation.

A particular book called the "patient chart" is rapidly being supplanted by computer-based hospital information systems. The management information system is more typical within hospital practice and is being used for such activities as the integration of laboratory data, drug monitoring, adverse effects reports, monitoring for drug interaction, and accounting and billing. We are beginning to see that expert systems can oversee the mechanics of the practice of medicine and provide some buffering against unintended errors. A sense of how these things operate will be indispensable to their efficient use by physicians.

In turning to some more general features, the use of computer technology can be divided into the learning process (in which the user is explicitly

a student), the practice process, and the research process, which provides the fundamental knowledge and expertise required for learning and practice. It is important that these not be too far apart. If they are not integrated within the same medium of communication, or if research, learning and practice cannot be expressed in a common language, or if they do not rely on a consistent database, then there is chaos, futility and disaster.

Computers are important factors in the research process, and computers in communications networks will have a role in the generation of scientific consensus in the research process. Many labs have their laboratory notebooks on-line with direct acquisition of data from experiments. This is a mechanical or engineering function of those systems. The new usage will be for the critical interaction of experts with one another: in an explicit community which may be working together on a particular problem or in an invisible college of individuals who may be exchanging information with one another. An example of the latter is the BIONET community sponsored by the National Institute of Health, which allows individuals working in the field of molecular genetics to share a common database—3 or 4 million characters of DNA nucleotide information assembled from around the world. A center in Philadelphia collects information for protein sequences. Los Alamos has the contract for DNA data. There is an international collaboration covering the European sector. BIONET itself is a shared resource, centered in a mainframe system in Menlo Park, California.

The learning uses of computers are those which most nearly approximate books. Here we have the role of the database retrieval system for bibliographic inquiries, the extension of MEDLINE which enables the student to discover what has been written. Although at the moment there is a limited amount of full-text material in such systems, one can generally get at the abstract or at least the title and key words as pointers to the library books. We are rapidly reaching the point where there will be two tiers of records in the scientific literature. There will be the paper publications, which will serve a function as gate-keeping indicators of recognition and prestige. The other, instant communication, or preprint level of dissemination, is already being taken over in many fields through sharing on computer-based communications media.

The computer can also provide a base in what is called computer-aided instruction or self-interrogation. Students can look at their mastery of the field in ways that are far more cost effective than having a professional tutor in constant attendance. The knowledge a physician needs can change overnight, but the physician's skills will have to persist. Acquiring skills such as adapting new information into one's framework of knowledge, to correlate this with the current art and

to check it for internal consistency can be done most effectively by student interaction with a knowledge base at the terminal.

The practice side of medicine would not be too different. As it becomes obvious that it is impossible to convey more than a fraction of contemporary knowledge, we must have more emphasis on continuing medical education as a part of the physician's career. Since physicians in practice will be far more diverse in their experience and new needs than are medical students, they will have even greater reliance on self-regulated, computer-aided learning systems.

The use of expert systems in medical practice may be tempered by patients' images of the profession. Will they accept the expertise of the information scientist—the one who best knows how to access the world's data—and pay the same fees as they do for the omniscience offered firsthand by the physician? Will they take more or less assurance from their doctor himself seeking a second opinion? Will doctors be able to sustain self-assurance in such an environment, or will this be resisted in a struggle to sustain the traditional image?

This decade has given us new and firm bridging between fundamental science in molecular biology, cell biology, and physiology and medicine, a pace of change that forces us to abandon the notion that the function of undergraduate medical education is to transmit the wisdom of a given year. Undergraduate medical education has to be thought of as the means to provide the base for a lifelong, continuing learning process. It will be impossible to manage that without the use of computer-based knowledge systems.

We now need new meta-systems to govern the logical structures of the expert systems themselves. But the hard part is yet to come, and that is in the extraction of the human expertise to be put into the systems. This is an unbelievably costly effort. If you have not yourself been the subject of a process which has tried to extract the knowledge you have in a given subject area, you are in for an interesting experience. The relentlessness of these systems, their demand that you say what you mean and that you mean what you say, and the extent to which rules that you impart are tested against all of the other instructions put into the system is quite a chastening experience for anyone, even in the field of his central expertise.

Current research and development in this field is concerned with more efficient ways of accomplishing knowledge extraction. This will require more intermediary languages so that experts can feel comfortable in expressing themselves in the habitual jargon of their own fields rather than through the somewhat stilted forms that most computer programs require. There are not many experts in knowledge engineering at the present time. There is little real science and much art in it, and only a few people have a history of practical

experience. We need more meta-systems to enhance efficiency. As long as print publication dominates the field, we need systems that can read the print literature more effectively.

The Defense Advanced Projects Research Agency has been the main sponsor of research on expert systems. Military decision-making imposes requirements on designs for computer-aided support that even exceed those in medicine and should have spillover advantages for our needs.

Characteristic of both medical and military systems, the real cost of development is in the building of the expertise, not in its use. A thousand dollars per rule is a very conservative estimate of the cost of building an expert system. If unpaid medical students participate in the development some of the true economic costs may be concealed, but this gives some notion of the costs of knowledge extraction and authentication.

Finally, what are the likely main uses of these new systems? Consider the integrity of the medical knowledge base on which the life or death of the patients depends, the integrity of the rules to reflect a wise consensus about the optimum form of therapy which incorporates in a consistent way all of the available information. I guess I am saying that I don't know how to do a human audit of the expert systems that have been brought together without an expert system to assist me in that process.

There is a deeper and more pervasive issue of how we are basing our entire economy, you might say our entire society, on rule systems that are formulated and managed by highly fragmented sets of experts such as the programmers in the banks and the people who run the credit systems. In a way, the system is essentially out of control. These people write the software; they deposit it deep in the bowels of the systems; they've never totally understood it, and this is now done in languages that are not subject to any consistent form of authentication and audit. Every one of us has had a disaster such as a phone bill with no bearing on anything that we had actually done. The question arises then as to whether one can rely on systems that have that kind of fallibility, not in the hardware but in the interaction of the knowledge that is put into the system, when as physicians we have the responsibility for managing

the welfare of the patient. So I think we need the meta-system for its editing expertise, so that the human intellect has some supportive tools to certify the integrity and authenticity of the expert systems we might rely on. ●



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